# Taguchi Method for Optimization of Cutting Parameters in Turning Operations

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*Abstract:* **Surface roughness an indicator of surface quality is one of the prime customer requirements for machined parts. For efficient use of machine tools, optimum cutting parameters are required. The turning process parameter optimization is highly complex and time consuming. In this paper taguchi parameter optimization methodology is applied to optimize cutting parameters in turning. The turning parameters evaluated are, cutting velocity, feed rate, depth of cut, and nose radius of tool and hardness of the material each at two levels. The results of analysis show that feed rate, cutting velocity and nose radius have present significant contribution on the surface roughness and depth of cut and hardness of material have less significant contribution on the surface roughness.**

*Index Terms* :**Taguchi method, surface roughness, turning parameters,optimization,orthogonal array,error analysis**

## I. INTRODUCTION

Surface roughness has formulated an important design features. It imposes one of the most critical constraints for the selection of machine tools and cutting parameters in process planning. Different procedures have been used by researchers from time to time for the process of optimization for example linear programming, quadratic programming, lagrangian multiplier, geometric program-ming, particle swarm optimization, genetic algorithm, taguchi method etc [1]. Taguchi method is an experimental method .It is effective methodology to find out the effective performance and machining conditions. Taguchi parameter design offers a simple, systematic approach and can reduce number of experiment to optimize design for performance, quality and manufacturing cost. Signal to noise ratio and orthogonal array are two major tools used in robust design. Robust design is a methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high quality products with low development and manufacturing costs. Genichi Taguchi is a Japanese engineer who has been active in the improvement of japans industrial products and process since the late 1940s he has developed both the philosophy and methodology for process or product quality improvement that depends heavily on statistical concepts and tool. Taguchi method refers to the parameter design, tolerance design, quality loss function, on line quality control, design of experiments using orthogonal arrays, methodology applied to evaluate measuring systems [1]. Taguchi ideas can be distilled into two fundamental concepts

(i) Quality losses must be defined as deviations from targets, not conformance to arbitrary specifications.
(ii) Achieving high system-quality levels economically requires quality to be designed into the product. Quality is designed, not manufactured, into the product.

The machinability of materials is determined by surface finish. Surface roughness and dimensional accuracy are the important factors required to predict machining parameters of any machining operations, optimization of machining parameters not only increases the utility for machining economics, but also the product quality increases to a great extent. In this context, an effort has been made to estimate the surface roughness using experimental data. Since turning is the primary operation in most of the production process in the industry, surface finish of turned components has greater influence on the quality of the product. Surface finish in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built up edge, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, stability of machine tool and work piece setup, and chatter, and use of cutting fluids [2]. Taguchi method consists of a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analyzing data, in order to obtain information about the behavior of a given process. It uses orthogonal arrays to define the experimental plans and the treatment of the experimental results is based on the analysis of variance (ANOVA)[2].

## II. LITERATURE REVIEW

Traditionally, the selection of cutting conditions for metal cutting is left to the machine operator. In such cases, the experience of the operator plays a major role, but even for a skilled operator it is very difficult to attain the optimum values each time. The main machining parameters in metal turning operations are cutting speed, feed rate and depth of cut etc. The setting of these parameters determines the quality characteristics of turned parts. K. Palanikumar, et al.[3] discussed the application of the Taguchi method with fuzzy logic to optimize the machining parameters for machining of GFRP composites with multiple characteristics. A multi-response performance index (MRPI) was used for optimization. The machining parameters like work piece (fiber orientation), cutting speed, feed rate, depth of cut, and machining time were optimized with consideration of multiple


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performance characteristics like metal removal rate, tool wear, and surface roughness. T. Srikanth and V. kamala [4] developed a real coded Genetic Algorithm (RCGA) approach for optimization of cutting parameters in turning. This RCGA approach is quite advantageous in order to have the minimum surface roughness values, and their corresponding optimum cutting parameters, for certain constraints [4]. S.S.Mahapatra et al.[2] an attempt has been made to generate a surface roughness prediction model and optimize the process parameters using Genetic algorithms. Adeel H. Suhail et al.[5] conducted experimental study to optimize the cutting parameters using two performance measures, work piece surface temperature and surface roughness. Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation. The experimental results showed that the work piece surface temperature can be sensed and used effectively as an indicator to control the cutting performance and improves the optimization process. T.G Ansalam Raj and V.N Narayanan Namboothiri [6] formed an improved genetic algorithm for the prediction of surface finish in dry turning of SS 420 materials.

## III. EXPERIMENTAL DETAILS

Classical experimental design methods are too complex and are not easy to use a large number of experiments have to be carried out when the number of process parameters increases. To solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments [6]. The experiments were carried out with five independent factors (cutting speed, feed rate, depth of cut, nose radius of cutting tool, hardness of work piece) and two interaction factors (cutting speed/depth of cut and feed rate/depth of cut) at two levels each. Here a standard L8 orthogonal array is used. The various factors and their levels are shown in table I and Table II shows standard L8 orthogonal array.

TABLE I
DIFFERENT FACTORS AND LEVELS

| Factors | 1 | 2 |
|---|---|---|
| -Cutting speed (m/min) | 30.615 | 24.492 |
| -Feed rate (mm/rev) | 0.274 | 0.112 |
| -Depth of cut (mm) | 1.2 | 0.8 |
| -Nose radius (mm) | 0.4 | 0.8 |
| -Hardness(BHN) | 160 | 170 |

TABLE II
STANDARD ORTHOGONAL ARRAY ($L_8$)

| Trial no | 1 (d) | 2 (r) | 3 (v) | 4 (vxd) | 5 (dxf) | 6 (f) | 7 (H) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| 3 | 1 | 2 | 2 | 1 | 1 | 2 | 2 |
| 4 | 1 | 2 | 2 | 2 | 2 | 1 | 1 |
| 5 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 6 | 2 | 1 | 2 | 2 | 1 | 2 | 1 |
| 7 | 2 | 2 | 1 | 1 | 2 | 2 | 1 |
| 8 | 2 | 2 | 1 | 2 | 1 | 1 | 2 |

### A. *Work piece material*

The work piece material used in the study was mild steel. They were in the form of cylindrical bar of diameter 32mm and length 100mm

### B. *Cutting tool material*

The cutting tool used in the study was HSS (10%) ½ inch x 4-inch length.

### C. *Machine tool*

The turning operation is carried out on a rigid lathe with 2.25kw (spindle speed 54-1200 rpm) motor drive.

### D. *Constraints*

Range of depth of cut (1.2 to 0.8mm).
Range of cutting speed (20- 35m/min for HSS).
Range of feed rate (0.048-0.716mm/rev).

## IV.RESULTS AND DISCUSSIONS

The experimental trials are conducted according to standard L8 orthogonal array. The surface roughness (Ra) is measured using surftest equipment and the results obtained are tabulated in table III and analysis of variance of the data with the surface roughness with the objective of the analyzing the influence of each variables on the total variance of the results is performed and the results obtained are tabulated in table IV. It shows percentage contribution of each parameter towards be surface roughness.

TABLE III
EXPERIMENTAL DESIGN USING $L_8$ ORTHOGONAL ARRAY

| Exp No | 1 (d) (mm) | 2 (r) (mm) | 3 (v) (m/min) | 4 (f) | BHN | $Ra_1$ (µm) | $Ra_2$ (µm) | Ra (average) (µm) |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1.60 | 1.44 | 1.52 |
| 2 | 1 | 1 | 1 | 2 | 2 | 1.30 | 1.20 | 1.25 |
| 3 | 1 | 2 | 2 | 2 | 2 | 1.30 | 1.50 | 1.40 |
| 4 | 1 | 2 | 2 | 1 | 1 | 1.40 | 1.80 | 1.60 |
| 5 | 2 | 1 | 2 | 1 | 2 | 1.82 | 1.82 | 1.82 |
| 6 | 2 | 1 | 2 | 2 | 1 | 1.45 | 1.55 | 1.50 |
| 7 | 2 | 2 | 1 | 2 | 1 | 1.00 | 1.10 | 1.05 |
| 8 | 2 | 2 | 1 | 1 | 2 | 1.45 | 1.45 | 1.45 |


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AMAE

TABLE IV
ANOVA TABLE FOR SURFACE ROUGHNESS.

| Factor | D.O.F | SUM OF Squares | Mean Squares | Percentage Contribution |
|---|---|---|---|---|
| D | 1 | 0.0218 | 0.0218 | 3.96 |
| R | 1 | 0.0996 | 0.0996 | 18.13 |
| V | 1 | 0.1750 | 0.1750 | 31.85 |
| Vxd | 1 | 0.0122 | 0.0122 | 2.22 |
| Dxf | 1 | 0.0004 | 0.0004 | 0.07 |
| F | 1 | 0.1987 | 0.1987 | 36.17 |
| H | 1 | 0.0416 | 0.0416 | 7.5 |
| Total | | 0.5493 | 0.5493 | 100 |

From the above table, it is observed that the cutting velocity (31.85%), feed rate (36.17%) and nose radius (18.13%) have great influence on surface roughness. The interactions of depth of cut /feed rate (0.07%) and cutting velocity/depth of cut (2.2%) have negligible influence. But the factor depths of cut (3.96%) and Hardness (7.5%) have present less significant contribution on the surface roughness. Since this is a parameter based optimization design, from the above values it is clear that feed rate is the prime factor to be effectively selected to get the good surface finish.

## V. REGRESSION ANALYSIS

The correlations between the factors (cutting speed, feed rate, depth of cut, nose radius and hardness) and surface roughness were obtained by regression analysis (running a program in matlab).

$R_a=1.27\ f^{\ 0.00528}d^{0.0013}v^{-0.0848}r^{-.0586}H^{-0.0903}$

Where $R_a$ is the surface roughness.

## VI. ERROR ANALYSIS

Some sources of uncertainty are addressable by statistical means; others are outside the scope of statistics. Uncertainty in experiment arises through at least three different processes: Uncertainties from definitions (example: meaning incomplete, unclear, or faulty definition).

Uncertainties from natural variability of the process.

Uncertainties resulting from the assessment of the process or quantity, including, depending on the method used,

- uncertainties from measuring;
- uncertainties from sampling;
- uncertainties from reference data that may be incompletely described; and
- uncertainties from expert judgment.

## VII.CHI-SQUARE TEST

Chi square test is conducted to check the feasibility of the test conducted. Here the expected value (E) is calculated using correlation obtained by regression analysis and it is shown in table V.

TABLE V
CHI-SQUARE TEST VALUES

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Observed Value(O) | 1.52 | 1.25 | 1.4 | 1.6 | 1.82 | 1.5 | 1.05 | 1.45 |
| Expected value (E) | 0.63 | 0.62 | 0.61 | 0.61 | 0.63 | 0.63 | 0.60 | 0.60 |
| $(O-E)^2/E$ | 1.26 | 0.66 | 1.01 | 1.63 | 2.2 | 1.18 | 0.35 | 1.22 |

$\chi^2 = \Sigma(O\text{-}E)^2/E = 9.496.$

Here degrees of freedom = n-1 = 7.

Taking a level of significance $\alpha$=0.05.

$\chi^2_{\alpha,n-1}$=14.067 (statistical table value)

Since $\chi^2<\chi^2_{\alpha,n-1}$ the sample is having goodness of fit.

## CONCLUSION

For solving machining optimization problems, various conventional techniques had been used so far, but they are not robust and have problems when applied to the turning process, which involves a number of variables and constraints. To overcome the above problems, Taguchi method is used in this work. Since Taguchi method is experimental method it is realistic in nature. According to this study the prime factor affecting surface finish is feed rate.

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